

Unit Summary
<p style="text-align: center;"><i>How can one explain the structure, properties, and interactions of matter?</i></p> <p>In this unit of study, students <i>develop and using models, plan and conduct investigations, use mathematical thinking, and construct explanations and design solutions</i> as they develop an understanding of the substructure of atoms and to provide more mechanistic explanations of the properties of substances. Chemical reactions, including rates of reactions and energy changes, can be understood by students at this level in terms of the collisions of molecules and the rearrangements of atoms. Students also apply an understanding of the process of <i>optimization and engineering design</i> to chemical reaction systems. The crosscutting concepts of <i>patterns, energy and matter, and stability and change</i> are the organizing concepts for these disciplinary core ideas. Students are expected to demonstrate proficiency in <i>developing and using models, planning and conducting investigations, using mathematical thinking, and constructing explanations and designing solutions</i>.</p>
Student Learning Objectives
<p>Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. <i>[Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.] (HS-PS1-7)</i></p>
<p>Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. <i>[Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.] (HS-PS1-4)</i></p>
<p>Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. <i>[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.] (HS-PS1-5)</i></p>
<p>Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* <i>[Clarification Statement: Emphasis is on the application of Le Chatlier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.] (HS-PS1-6)</i></p>
<p>Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. (HS-ETS1-2)</p>

Quick Links		
Unit Sequence p. 2	Modifications p. 6	Connections to Other Courses p. 9
What it Looks Like in the Classroom p. 4	Research on Learning p. 7	Links to Free and Low Cost Instructional Resources p. 10
Connecting with ELA/Literacy and Math p. 5	Prior Learning p. 7	Appendix A: NGSS and Foundations p. 12

Part A: Where do the atoms go during a chemical reaction?	
Concepts	Formative Assessment
<ul style="list-style-type: none"> The fact that atoms are conserved, together with the knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. The total amount of energy and matter in closed systems is conserved. The total amount of energy and matter in a chemical reaction system is conserved. Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. Changes of energy and matter in a chemical reaction system can be described in terms of energy and matter flows into, out of, and within that system. 	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> Use mathematical representations of chemical reaction systems to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. Use mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale, using the mole as the conversion from the atomic to the macroscopic scale. Use the fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, to describe and predict chemical reactions. Describe changes of energy and matter in a chemical reaction system in terms of energy and matter flows into, out of, and within that system.

Part B: What is different inside a heat pack and a cold pack?	
Concepts	Formative Assessment
<ul style="list-style-type: none"> A stable molecule has less energy than the same set of atoms separated; at least this much energy must be provided in order to take the molecule apart. Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. Changes of energy and matter in a chemical reaction system can be 	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> Explain the idea that a stable molecule has less energy than the same set of atoms separated. Describe changes of energy and matter in a chemical reaction system in terms of energy and matter flows into, out of, and within that system. Describe chemical processes, their rates, and whether or not they store or

<p>described in terms of collisions of molecules and the rearrangements of atoms into new molecules, with subsequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.</p> <ul style="list-style-type: none"> Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. 	<p>release energy in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.</p> <ul style="list-style-type: none"> Develop a model based on evidence to illustrate the relationship between the release or absorption of energy from a chemical reaction system and the changes in total bond energy.
---	---

Part C: Is it possible to change the rate of a reaction or cause two elements to react that do not normally want to?

Concepts	Formative Assessment
<ul style="list-style-type: none"> Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Patterns in the effects of changing the temperature or concentration of the reacting particles can be used to provide evidence for causality in the rate at which a reaction occurs. 	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> Use the number and energy of collisions between molecules (particles) to explain the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Use patterns in the effects of changing the temperature or concentration of the reactant particles to provide evidence for causality in the rate at which a reaction occurs. Apply scientific principles and multiple and independent student-generated sources of evidence to provide an explanation of the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Part D: What can we do to make the products of a reaction stable?

Concepts	Formative Assessment
<ul style="list-style-type: none"> Much of science deals with constructing explanations of how things change and how they remain stable. In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of 	<p><i>Students who understand the concepts are able to:</i></p> <ul style="list-style-type: none"> Construct explanations for how chemical reaction systems change and how they remain stable. Design a solution to specify a change in conditions that would produce

<p>molecules present.</p> <ul style="list-style-type: none"> Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others may be needed. Explanations can be constructed explaining how chemical reaction systems can change and remain stable. 	<p>increased amounts of products at equilibrium in a chemical system based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</p> <ul style="list-style-type: none"> Break down and prioritize criteria for increasing amounts of products in a chemical system at equilibrium. Refine the design of a solution to specify a change in conditions that would produce increased amounts of products at equilibrium in a chemical system based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
--	---

What It Looks Like in the Classroom

The *Bonding and Chemical Reaction* unit ties together the concepts developed in *Structure and Properties of Matter* and *Energy and its Applications in Abiotic Systems* units (how to describe and predict chemical reactions, and energy flow and conservation within a system). In this unit, students will develop an understanding that the total amount of energy and matter in a closed system (including chemical reaction systems) is conserved and that changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. Using this knowledge, and knowledge of the chemical properties of elements, students should be able to describe and predict simple chemical reactions in terms of mass and energy.

The mole concept and stoichiometry are used to show proportional relationships between masses of reactants and products. Students should be able to use balanced equations to show mass relationships between reactants and products. Students should also gain an understanding of the use of dimensional analysis to perform mass to mole conversions that demonstrate how mass is conserved during chemical reactions. Focus should be on students' use of mathematics to demonstrate their thinking about proportional relationships among masses of reactants and products and to make connections between the atomic and macroscopic world. Students should use units appropriately and consistently, considering limitations on measurement, for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.

This unit also expands student understanding of the conservation of energy within a system by emphasizing the key idea that a stable molecule has less energy than the same set of atoms when separated. To support this concept, students might look at the change in energy when bonds are made and broken in a reaction system. Students might also analyze molecular-level drawings and tables showing energies in compounds with multiple bonds to show that energy is conserved in a chemical reaction.

In addition to conservation of energy, students should explore energy flow into, out of, and within systems (including chemical reaction systems). Students might be given data and asked to graph the relative energies of reactants and products to determine whether energy is released or absorbed. They should also conduct simple chemical reactions that allow them to apply the law of conservation of energy by collecting data from their own investigations. Students should be able to determine whether reactions are endothermic and exothermic, constructing explanations in terms of energy changes. These experiences will allow them to develop a model that relates energy flow to changes in total bond energy. Examples of models might include molecular-level drawings, energy diagrams, and graphs.

Students should expand their study of bond energies by relating this concept to kinetic energy. This can be understood in terms of the collisions of molecules and the rearrangement of atoms into new molecules as a function of their kinetic energy content. Students should also study the effect on reaction rates of changing the temperature and/or concentration of a reactant (Le Chatelier's principle). Students might explore the concept of equilibrium through investigations, which may include manipulations of variables such as temperature and concentration. Examples of these investigations may include the iodine clock reaction, the ferrous cyanide complex, as well as computer simulations such as those located at www.harpercollege.edu/tm-ps/chm/100/dgodambe/thedisk/equil/equil.htm. Using results from these investigations, students should develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs and on equilibrium. Students should be able cite evidence from text to support their explanations after conducting research.

Finally, in order to meet the engineering requirement for Unit 3, students should design a solution to specify a change in conditions that would produce increased amounts of products at equilibrium. As they consider their design, students should keep in mind that much of science deals with constructing explanations for how things change and how they remain stable. Through investigations and practice in changing reaction conditions (as mentioned above), as well as through teacher demonstrations such as MOM to the Rescue/Acid-Base Reaction (Flinn Scientific), students should come to understand that in many situations, a dynamic and condition dependent balance between a reaction and the reverse reaction determines the number of all types of molecules present. Examples of designs that students could refine might include different ways to increase product formation. Designs should include methods such as adding reactants or removing products as a means to change equilibrium. Students will base these design solutions on scientific knowledge, student-generated sources of evidence from prior investigations, prioritized criteria, and tradeoff considerations. They will do this in order to produce the greatest amount of product from a reaction system.

Integration of engineering -

The engineering performance expectation HS-PS1-1 calls specifically for a connection to HS-ETS1.C. To meet this requirement, HS-ETS1-2 has been identified as appropriate for this unit, since it directs students to design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. Students will design a solution to specify a change in conditions that would produce increased amounts of products at equilibrium.

Connecting with English Language Arts/Literacy

English Language Arts/Literacy

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations showing that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support the concept that changing the temperature or concentration of the reacting particles affects the rate at which a reaction occurs.
- Develop an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples.
- Construct short as well as more sustained research projects to answer how to increase amounts of products at equilibrium in a chemical system. Synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

Mathematics

- Represent an explanation that atoms, and therefore mass, are conserved during a chemical reaction symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the conservation of atoms and mass during chemical reactions symbolically and manipulate the representing symbols.
- Use units as a way to understand the conservation of atoms and mass during chemical reactions; choose and interpret units consistently in formulas representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale; choose and interpret the scale and origin in graphs and data displays representing the conservation of atoms and mass in chemical reactions.
- Define appropriate quantities for the purpose of descriptive modeling of the proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing proportional relationships between masses of atoms in the reactants and products and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale.
- Use a mathematical model to explain how the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs symbolically and manipulate the representing symbols.
- Use units as a way to understand an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret units consistently in formulas representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. Choose and interpret the scale and the origin in graphs and data displays representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- Use a mathematical model to explain how to increase amounts of products at equilibrium in a chemical system. Identify important quantities in the cycling of matter and flow of energy among organisms in an ecosystem, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

Modifications

Teacher Note: Teachers identify the modifications that they will use in the unit. The unneeded modifications can then be deleted from the list.

- Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA)
- Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community.

- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences).
- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.
- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.

Research on Student Learning

Middle- and high-school student thinking about chemical change tends to be dominated by the obvious features of the change. For example, some students think that when something is burned in a closed container, it will weigh more because they see the smoke that was produced. Further, many students do not view chemical changes as interactions. They do not understand that substances can be formed by the recombination of atoms in the original substances. Rather, they see chemical change as the result of a separate change in the original substance, or changes, each one separate, in several original substances. For example, some students see the smoke formed when wood burns as having been driven out of the wood by the flame ([NSDL, 2015](#)).

Prior Learning

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using models of matter. Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change. Some chemical

reactions release energy; others store energy.

- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun.
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object or a ball, respectively).
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- A system of objects may also contain stored (potential) energy, depending on their relative positions.
- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object or a ball, respectively).
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- A system of objects may also contain stored (potential) energy, depending on their relative positions. Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

Life science

- Plants, algae (including phytoplankton), and many microorganisms use energy from light to make sugars (food) from carbon dioxide from the atmosphere and water, through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.
- Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules to support growth or to release energy.
- Food webs are models that demonstrate how matter and energy are transferred among producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled

repeatedly between the living and nonliving parts of the ecosystem.

Earth and space sciences

- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.
- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.

Connections to Other Courses

Physical science

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position) of the particles. In some cases, the relative position of energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Life science

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells.
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical

process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.

- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

Links to Free and Low Cost Instructional Resources

Note- The majority of the student sense-making experiences found at these links predate the NGSS. Most will need to be modified to include science and engineering practices, disciplinary core ideas, and cross cutting concepts. [The EQulP Rubrics for Science](#) can be used as a blueprint for evaluating and modifying instructional materials.

- American Association for the Advancement of Science: <http://www.aaas.org/programs>
- American Chemical Society: <http://www.acs.org/content/acs/en/education.html>
- Concord Consortium: Virtual Simulations: <http://concord.org/>
- International Technology and Engineering Educators Association: <http://www.iteaconnect.org/>
- National Earth Science Teachers Association: <http://www.nestanet.org/php/index.php>
- National Science Digital Library: <https://nsdl.oercommons.org/>
- National Science Teachers Association: <http://ngss.nsta.org/Classroom-Resources.aspx>
- North American Association for Environmental Education: <http://www.naaee.net/>
- Phet: Interactive Simulations <https://phet.colorado.edu/>
- Science NetLinks: <http://www.aaas.org/program/science-netlinks>

Appendix A: NGSS and Foundations for the Unit
<p>Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. <i>[Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.]</i> (HS-PS1-7)</p>
<p>Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. <i>[Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.]</i> (HS-PS1-4)</p>
<p>Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. <i>[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]</i> (HS-PS1-5)</p>
<p>Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* <i>[Clarification Statement: Emphasis is on the application of Le Chatlier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]</i> (HS-PS1-6)</p>
<p>Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. (HS-ETS1-2)</p>

The Student Learning Objectives above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Developing and Using Models</p> <ul style="list-style-type: none"> Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS1-4),(HS-PS1-8) Use a model to predict the relationships between systems or between components of a system. (HS-PS1-1) <p>Planning and Carrying Out Investigations</p> <ul style="list-style-type: none"> Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS1-3) <p>Using Mathematics and Computational Thinking</p> <ul style="list-style-type: none"> Use mathematical representations of phenomena to support claims. (HS-PS1-7) <p>Constructing Explanations and Designing Solutions</p> <ul style="list-style-type: none"> Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS1-5) Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-PS1-2) 	<p>PS1.A: Structure and Properties of Matter</p> <ul style="list-style-type: none"> Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1) The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1),(HS-PS1-2) The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3),(secondary to HS-PS2-6) A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-4) <p>PS1.B: Chemical Reactions</p> <ul style="list-style-type: none"> Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-4),(HS-PS1-5) In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6) 	<p>Patterns</p> <ul style="list-style-type: none"> Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-1),(HS-PS1-2),(HS-PS1-3),(HS-PS1-5) <p>Energy and Matter</p> <ul style="list-style-type: none"> In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-8) The total amount of energy and matter in closed systems is conserved. (HS-PS1-7) Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS1-4) <p>Stability and Change</p> <ul style="list-style-type: none"> Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-6) <p>-----</p> <p>Connections to Nature of Science</p> <p>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</p> <ul style="list-style-type: none"> Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS1-7)

<ul style="list-style-type: none"> Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS1-6) <p>Asking Questions and Defining Problems</p> <ul style="list-style-type: none"> Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1) <p>Using Mathematics and Computational Thinking</p> <ul style="list-style-type: none"> Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4) <p>Constructing Explanations and Designing Solutions</p> <ul style="list-style-type: none"> Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2) Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3) 	<ul style="list-style-type: none"> The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7) <p>PS1.C: Nuclear Processes</p> <ul style="list-style-type: none"> Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8) <p>PS2.B: Types of Interactions</p> <ul style="list-style-type: none"> Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.(secondary to HS-PS1-1),(secondary to HS-PS1-3) <p>ETS1.C: Optimizing the Design Solution</p> <ul style="list-style-type: none"> Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS1-6) <p>ETS1.A: Defining and Delimiting Engineering Problems</p> <ul style="list-style-type: none"> Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize 	
--	---	--

	<p>pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)</p> <p>ETS1.B: Developing Possible Solutions</p> <ul style="list-style-type: none">• When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)• Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4) <p>ETS1.C: Optimizing the Design Solution</p> <ul style="list-style-type: none">• Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	
--	--	--

Embedded English Language Arts/Literacy and Mathematics	
<i>English Language Arts/Literacy</i>	
RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-PS1-1)
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-5)
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ETS1-1),(HS-ETS1-3)
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-1),(HS-ETS1-3)
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-ETS1-1),(HS-ETS1-3)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS1-5)
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS1-6)
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-PS1-4)
<i>Mathematics -</i>	
MP.2	Reason abstractly and quantitatively. (HS-PS1-5),(HS-PS1-7),(HS-ETS1-1),(HS-ETS1-3),(HS-ETS1-4)
MP.4	Model with mathematics. (HS-PS1-4), (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4)
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-4),(HS-PS1-5),(HS-PS1-7),(HS-PS1-8)

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-4),(HS-PS1-7)

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS1-4),(HS-PS1-5),(HS-PS1-7)

DRAFT